5.5.3 Cosmology

Learning outcomes		Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	distances measured in astronomical unit (AU), light-year (ly) and parsec (pc)	*M4.6*
(b)	stellar parallax; distances the parsec (pc)	
(c)	the equation $p = \frac{1}{d}$, where p is the parallax in seconds of arc and d is the distance in parsec	

(6) M - Define Stella parallax
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(8) C - Apply the equations relating the parallax p and the distance d in parsecs

Astronomical distances

STARTER: Self assess HWK

Star name	Luminosity (L/L_{Sun})	Temperature / K	Peak wavelength / nm	Radius (r/r_{Sun})	Type of star
Sirius	25	9940	**292**	1.7	**Main sequence**
Canopus	13 600	**7350**	395	65	**Supergiant**
Arcturus	**170**	**4300**	674	26	Giant
Capella	79	4940	587	**12**	**Giant**
Vega	37	**9600**	**302**	**2.3**	Main sequence
Rigel A	66 000	**11 000**	264	**78**	**Supergiant**
Procyon B	**0.000 49**	7740	**375**	0.0012	**White dwarf**

Question

a $\lambda_{max} T = 0.0029$

$\lambda_{max} = \frac{0.0029}{3590} \rightarrow 8.08 \times 10^{-7}$ m (= 808 nm)

(1 mark for substitution and manipulation, 1 mark for answer)

b Graph should be similar to the red (6000 K) graph in the worksheet, with the peak wavelength labelled as 808 nm. Students may have drawn a similar graph to the 3000 K graph, but this would not gain the marks as it is not using the available space. The graphs are similar shapes but different scales. *(1 mark for correct shape, 1 mark for correctly labelled wavelength, 1 mark for filling the axes)*

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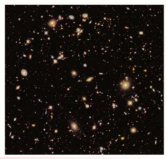
Astronomical distances

STARTER: What proportion of the night sky is this photo?



Extension: What difficulties do we have finding the distance of these obejcts? How could we find the distance of all of these objects?

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Astronomical distances

The light-year

Key definition: The distance travelled by light through a vacuum in one year.

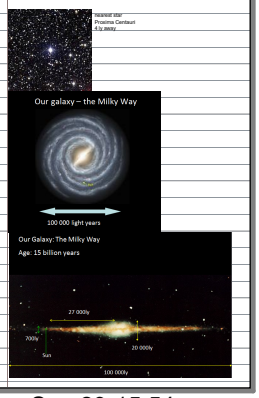
Ex: Calculate how many metres there are in 1 ly. 9.46×10^{15} m

The astronomical unit (AU)

Key definition: The average distance of the Earth from the Sun

1 AU = 1.496×10^{11} m

Parsec (pc) ????



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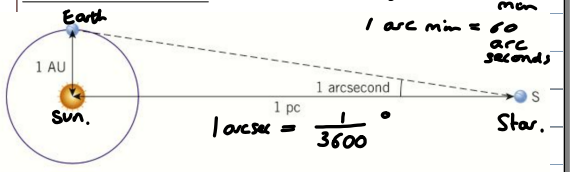
Astronomical distances



1 degree → 60 arc min
1 arc min = 60 arc seconds
1 arcsec = $\frac{1}{3600}$ °

▲ Figure 3 *The parsec is defined using the astronomical unit*

The **parsec** is defined as the distance at which a radius of one AU subtends an angle of one arc second.

Activity: Find the distance of one parsec in m. and in Ly (Ex)

$1 pc = \tan\left(\frac{1}{3600}\right) = \frac{1 AU}{1 PC}$

Ex: What science is incorrect here and why?

$1PC = \frac{1AU}{\tan\left(\frac{1}{3600}\right)}$

$= 3.09 \times 10^{16}$ m

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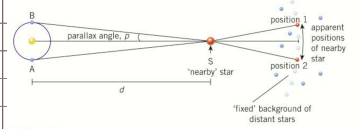
Parallax method. parallax

Activity: Use the video and text book to state and explain how stellar parallax is used to measure the distance of a nearby star in space.

Use a diagram to support your answer.



Answer:

1. Apparent motion or displacement of a star relative to the position of more distant stars.
2. Caused by the Earth's orbit around the Sun, and the star observed from different positions.
3. An angle of parallax of 1 arcsecond when displacement of Earth is 1AU corresponds to distance 1 pc

Parallax angle is measured in arc seconds (not degrees).

1 arc second = $\frac{1}{3600}$ degrees

If p is measure in arc seconds, the distance to the nearby star in parsecs is given by:

$d = \frac{1}{p}$

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Activity: Complete the table to find the distance of each star.

Star	p/arc sec	d/ly	d/pc	$p \times d$/pc arc sec
Altair	0.20			
Arcturus	0.090			
Capella	0.073			
Sirius	0.38			
Vega	0.12			

Ex: explain and make a comment of the value of the last column for each star.

a

Star	p/arc sec	d/ly	d/pc	$p \times d$/pc arc sec
Altair	0.20	16	4.85	0.97
Arcturus	0.090	36	10.9	0.98
Capella	0.073	45	13.6	0.99
Sirius	0.38	8.7	2.64	1.00
Vega	0.12	26	7.88	0.95

b Since $d = \frac{1}{p}$, the product of d in parsec and p in arc second must be equal to one.

That is: $pd = 1$.

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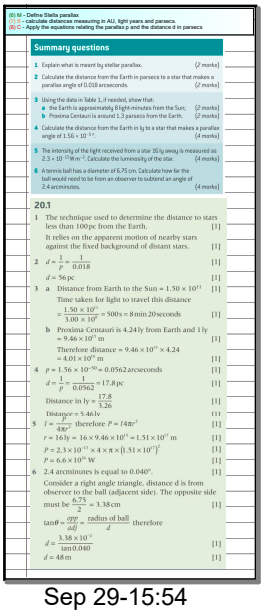

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Summary questions

1 Explain what is meant by stellar parallax. (2 marks)

2 Calculate the distance from the Earth in parsecs to a star that makes a parallax angle of 0.018 arcseconds. (2 marks)

3 Using the data in Table 1, if needed, show that:
a the Earth is approximately 8 light-minutes from the Sun; (2 marks)
b Proxima Centauri is around 1.3 parsecs from the Earth. (2 marks)

4 Calculate the distance from the Earth in ly to a star that makes a parallax angle of 1.56×10^{-5}°. (4 marks)

5 The intensity of the light received from a star 35 ly away is measured as 2.3×10^{-13} W m^{-2}. Calculate the luminosity of the star. (4 marks)

6 A tennis ball has a diameter of 6.75 cm. Calculate how far the ball would need to be from an observer to subtend an angle of 2.4 arcminutes. (4 marks)

20.1

1 The technique used to determine the distance to stars less than 100 pc from the Earth. [1]
It relies on the apparent motion of nearby stars against the fixed background of distant stars. [1]

2 $d = \frac{1}{p} = \frac{1}{0.018}$ [1]
$d = 56$ pc [1]

3 a Distance from Earth to the Sun $= 1.50 \times 10^{11}$ [1]
Time taken for light to travel this distance
$= \frac{1.50 \times 10^{11}}{3.00 \times 10^{8}} = 500$ s $= 8$ min 20 seconds [1]

b Proxima Centauri is 4.24 ly from Earth and 1 ly $= 9.46 \times 10^{15}$ m [1]
Therefore distance $= 9.46 \times 10^{15} \times 4.24$
$= 4.01 \times 10^{16}$ m [1]

4 $p = 1.56 \times 10^{-5}° = 0.0562$ arcseconds [1]
$d = \frac{1}{p} = \frac{1}{0.0562} = 17.8$ pc [1]
Distance in ly $= \frac{17.8}{3.26}$ [1]
Distance $= 5.46$ ly [1]

5 $I = \frac{L}{4\pi r^2}$ therefore $P = I4\pi r^2$ [1]
$r = 16$ ly $= 16 \times 9.46 \times 10^{15} = 1.51 \times 10^{17}$ m [1]
$P = 2.3 \times 10^{-13} \times 4 \times \pi \times (1.51 \times 10^{17})^2$ [1]
$P = 6.6 \times 10^{16}$ W [1]

6 2.4 arcminutes is equal to 0.040°. [1]
Consider a right angle triangle, distance d is from observer to the ball (adjacent side). The opposite side must be $\frac{6.75}{2} = 3.38$ cm [1]
$\tan\theta = \frac{\text{opp}}{\text{adj}} = \frac{\text{radius of ball}}{d}$ therefore
$d = \frac{3.38 \times 10^{-2}}{\tan 0.040}$ [1]
$d = 48$ m [1]

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Mini plenary

Antares is a red giant and one of the brightest stars in the night sky. The parallax angle for this star is 0.0059 arc seconds.

Calculate its distance in light years from us.
1 pc = 3.26 ly

distance = _____ ly **[2]**

Answer: (parallax = 1/*d*)
$d = 0.0059^{-1}$ (pc = 169 .49 .... pc)

distance = $0.0059^{-1} \times 3.26$
distance = 550 ly

Marks: C1
A1

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Plenary G

5 **a** What is meant by *stellar parallax*? [2]
b The first recorded stellar parallax had a value of 0.314 arc seconds.
i Calculate the distance of the star from Earth, giving your answer in parsecs. [2]
ii What is this distance in metres? [1]
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Answer

a Stellar parallax is the apparent shifting of the position of a star against the background of distant stars. [1]
This is due to the star being observed from different positions in the Earth's orbit. [1]

b **i** Distance (pc) $= \frac{1}{\text{parallax (arc seconds)}}$ [1]
Distance $= \frac{1}{0.314 \text{ arc seconds}}$
Distance $= 3.18$ pc [1]
ii 1 pc $= 3.1 \times 10^{16}$ m
Distance $= 3.18 \times 3.1 \times 10^{16} \simeq 9.9 \times 10^{16}$ m [1]

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